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Design Considerations for the Small Scientific Satellite (S3)

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Summary

The Small Scientific Satellite (S^3) program has been established to provide a highly sophisticated Scout class system for individual experimenters or small groups of experimenters to conduct specialized studies of specific phenomena in the magnetosphere or near interplanetary space. The spacecraft system is designed to be as flexible as possible to accommodate a wide variety of scientific missions to be flown in the next decade. This paper describes the methods used to obtain design guidelines through extensive interviews with potential users and the resultant design concepts.

Introduction

The Small Scientific Satellite (S^3) program was originally conceived to extend the radiation belt and magnetospheric investigations begun by the Energetic Particle Explorer (EPE) series (Explorers XII, XIV, XV and XXVI). Explorers XII, XIV and XV identified the termination of radiation belts by the magnetospheric boundary and studied the distribution of charged particles throughout the magnetosphere. They also discovered the presence of protons in the outer radiation zone and established the general temporal stability and instability levels of the various species of energetic charged particles in the radiation zone.

Explorer XXVI, the last in the EPE series, was launched on December 21, 1964. Several magnetic storms were observed during its useful lifetime of two and one-half years. Observations of the variation in charged particle intensities during the magnetic field decrease gave the first positive indications of a magnetic storm associated ring current. There is reason to believe that the many transient phenomena occurring in the magnetosphere, such as particle acceleration, particle redistribution, field fluctuations, aurora and some VLF emissions, are closely related and perhaps are driven by energy derived from the solar plasma impinging on the magnetosphere. However, there are no adequate physical theories at present to explain and relate these transient phenomena.

Even before the launching of Explorer XXVI, scientists at the Goddard Space Flight Center (GSFC) began stressing the importance of continuing their magnetospheric investigations. Specific studies were suggested to include energetic particle intensities, pitch angle distributions, energy spectra, magnetic field intensities and directions, electric fields and electromagnetic and plasma waves. It would be necessary to plan detailed investigations of possible correlations between these phenomena. The Goddard scientists proposed a design study to determine the desirability and feasibility of developing a small, Explorer-class spacecraft system to continue the study of the magnetosphere.

Feasibility Study

A feasibility study was initiated in mid-1965. During the early phase of the study, considerable effort was placed on soliciting functional and operational requirements from several groups of experienced experimenters throughout the country. Thirty-eight scientists representing nineteen research laboratories were interviewed. Their fields of interests encompassed Energetic Particles, A.C. Fields-VLF, D.C. Fields-B and E, Plasmas, Atmospheric Physics, Ionospheric Physics, Solar Physics, Auroral Photometry, and X-Ray and Gamma-Ray Astronomy. They were asked to project their system and subsystem requirements for several years into the future. An eight page questionnaire was prepared and used to record their inputs. Typical requirements probed were: Orbit parameters, spacecraft position accuracy, stabilization, lifetime, etc.; mechanical interface including mounting and location of sensors, weight and volume of sensors and electronics, limiting dimensions, presence of moving mechanisms, etc.; power requirements including average, peak, duty cycle, unusually high voltages; environmental constraints such as temperature, magnetic, Rf, outgassing, electric potentials; data system requirements such as types and number of outputs, sampling conditions, feasibility of on-board processing or computations to reduce transmission of raw data, mode changes, timing signal requirements, and so forth. Finally, a general question was asked as to what present spacecraft design philosophies most limit their experimentation, and consequently, what new features would be most desirable.

Several interesting ideas emerged from this exchange of information. First, by the late sixties and early seventies, most of the exploratory scientific work should have been done. Scientists will then be attacking specific problems which will require the close cooperation of several experimenters. A complete mission will be proposed consisting of a tightly integrated experiment payload, to be placed in a specific orbit, and with total data exchange. A small satellite seems best suited for such needs. Secondly, reaction time with presently available spacecraft is too long. On the larger Observatory programs, it is not unusual for four or five years to elapse between experiment proposal and launch. A small satellite, with well defined electrical and mechanical interface specifications, should reduce this time to 18 months. Spacecraft integration would begin approximately six months before launch. This not only helps in the timely solution of experimental problems, but also enables the participation of graduate students in the scientific programs. Thirdly, the plan is to develop the first S^3 as an in-house project at the GSFC. Subsequent spacecraft will be fabricated, integrated, tested and launched by a prime contractor under the direction of the GSFC management team. Scientific groups will supply only their experiment subsystems. This was a very important feature to the experimenters. Most groups do not have the administrative and engineering support to handle an entire spacecraft program. They would much prefer to concentrate their efforts on the experiment complement.

The detailed information from the questionnaires was tabulated in order to establish guidelines for the GSFC subsystem designers. The intent was to develop a basic spacecraft design to accommodate a large variety of experiments and to be used for many different missions. Obviously, not all experimenter requirements can be met. However, it is hoped that the approach being taken on the S^3 program will result in a useful research tool to be used by the scientific community for the next decade.

The Feasibility Study[1] was published in March 1966. A formal Project Proposal was submitted to NASA Headquarters in July 1966. Approval was received in January 1967 for two missions plus long lead time development for experiments for two additional planned missions. As previously mentioned, the first spacecraft will be a GSFC in-house development with follow-on spacecraft built by a prime contract to GSFC's specifications and under the direction of the GSFC management team.

S^3 Design Concepts

Two basic design guidelines from the beginning of the program have been flexibility and small size. Flexibility is important for the S^3 spacecraft to accommodate a variety of scientific missions without the need for continual redesign and requalification of subsystems. We have sized the S^3 to be compatible with the Scout launch vehicle. With a spacecraft weight of 80 to 90 pounds, missions which require orbits with apogees to six earth radii geocentric can be accomplished with the four-stage Scout. A five stage version of the Scout is under development that will place a spacecraft in this same weight range out to 30 earth radii. Naturally, the four-stage Scout can handle significantly larger spacecraft weights for near earth missions.

Figure 1 shows the configuration for the first S^3, or S^3-A, to be launched in late 1969 or early 1970. The scientific mission is to investigate the ring-current and magnetic storms; the relations between auroral phenomena, magnetic storms and charged particles within the magnetosphere; and the time variations of the trapped particle population. The basic spacecraft is a 26-sided polyhedral shape approximating a 27-inch diameter sphere. This shape was chosen to produce a nearly uniform output from the solar array at any angle to the sun and also for ease of passive thermal control. There is sufficient room within the 30-inch diameter Scout heat shield to fold appendages along the sides of the spacecraft. The spacecraft is spin stabilized for the S^3-A mission. The boom along the spin axis supports a three-axis fluxgate magnetometer and flipper mechanism enclosed in a protective globe. The fluxgate magnetometer is boom mounted to be as far removed as practical from the magnetic background exhibited by the spacecraft. Although the S^3-A mission will use the four-stage Scout, we're taking advantage of a 15 inch extended heat shield being developed for the five-stage Scout in order to maximize the magnetometer boom length. With this configuration, radial booms are required for sufficient roll moment of inertia. Search coil magnetometers are packaged on two of the radial booms in order to minimize the amount of dead weight necessary for roll stability. In like manner, a third radial boom will house a small magnetometer sensor and associated electronics for operation of the magnetic torquing attitude and spin rate control system. The fourth radial boom is for inertia purposes only. The radial booms are held in the stowed position by the "yo-yo" despin system. The other identifiable features shown in figure 1 will be discussed in later sections describing the primary spacecraft subsystems. The spacecraft will be designed for a one year nominal lifetime.

Mechanical Design

The S^3 engineering test unit structure is pictured in figure 2. The structure consists of the lower, middle and upper sections and weighs approximately 10 pounds. It is primarily constructed of riveted aluminum sheet metal in order to minimize weight and cost.

The lower section carries the primary load and is composed of the center tube, an interface ring and the lower support structure. The center tube is a rolled and riveted sheet aluminum tube 9 inches in diameter and 14 inches long. It houses the battery pack and tape recorder. The tube is riveted to the machined aluminum interface ring which, in turn, is bolted to the Scout "E" section adapter. This allows for the disassembly of the spacecraft from the Scout motor without disturbing the separation system and clamp. Subsequent reassembly can be accomplished without the need for rebalancing the combined spacecraft and motor. The lower support structure is formed from sheet aluminum and includes 8 radial struts and an octagonal experiment support deck. The struts are riveted to the center tube and support deck. Trapezoidal shaped solar cell panels will be attached to each facet.

The mid-section houses most of the instrumentation and experiment subsystems. This section resembles a Ferris wheel with an upper and lower sheet aluminum "spider" separated by formed vertical spacers. Experiments and electronics are packaged in trapezoidal shaped frames that are plugged in from the periphery of the Ferris wheel. Each frame has a cross-sectional area of approximately 40 square inches and the frame height can very from $\frac{1}{2}$ inch to 8 inches in half inch increments. Four of the wheel sectors will be occupied by the basic spacecraft subsystems with the remaining 4 sectors available to experimenters. The spacecraft wiring harness is affixed in the center portion of the wheel. Insertion and removal of the subsystem frames can be accomplished without handling the harness, thus enhancing reliability. Rectangular solar cell panels will be attached to all facets not interrupted by experiment apertures.

The upper section is a sheet aluminum riveted assembly consisting of top cap, stringers and ring. It is used primarily to support the upper solar cell panels. On the S^3-A mission, the support for the fluxgate magnetometer boom and the coils for the attitude and spin rate control system are located in this section.

A weight summary for the S^3-A mission is shown in figure 3. Total weight is the critical factor for this mission. For missions requiring higher apogees, the basic spacecraft weight of 79 pounds could be reduced to less than 70 pounds by deleting some of the options such as attitude and spin rate control and redundant aspect determination systems. On the other hand, with increases in some subsystem weights, experiments weighing 50 pounds can be handled with a total spacecraft weight of 150 pounds. With slight modifications to the lower structure, significantly larger experiment weights can be accommodated to take advantage of the Scout capability for low circular orbits. It is estimated that experiments in the 150-170 pound class could be handled with a total orbital weight of 280 pounds.

The S^3 structural concept is thought to combine the best features of low cost, simplicity in design and fabrication, ease of assembly, standardization of hardware, ease of mechanical and electrical integration and test, interchangeability of subsystems, vibration damping, and ease of thermal control. The concept is an important part of the overall requirement for the spacecraft to be adaptable to a variety of scientific missions.

Electrical Design

The basic S^3 block diagram is shown in figure 4. The power system consists of a solar array, battery, solar array shunt regulator, battery charger, battery discharge regulator, and instrumentation converter. The solar array is paralleled by the shunt regulator, the battery with its series charge regulator and discharge regulator, and the instrumentation converter. Battery charge control and array bus voltage limiting are provided by the battery charge regulator and shunt regulator. The shunt regulator is used to limit the maximum bus voltage to 28 volts +2 percent by dissipating the excess solar power not required by the spacecraft loads or battery. The charge regulator, located in series between the array and battery, functions to regulate battery charge in accordance with a prescribed charge method for the type of battery used. To prevent overloading of the array during battery charging, the regulator is provided with bus voltage feedback. The battery and its discharge regulator is used to limit the bus voltage to a minimum of 28 volts -2 percent during periods when the spacecraft loads exceed the capacity of the array. When the available array power is adequate, the regulator remains in a standby condition sensing the main bus voltage.

The instrumentation converter operates from the 28 volt bus and provides regulated voltages to those subsystems that would be common to nearly all missions. Other spacecraft subsystems peculiar to a particular mission and the experiment complement will interface with the main bus through separate converters to provide the required voltage levels and regulation. To accommodate the requirements of VLF experiments, the converters will switch power at a minimum of 20 KC. To satisfy experiments with high frequency requirements, additional provisions such as shielding and filtering will be added to suppress noise from the converters.

The power requirements for S^3-A are tabulated in figure 5. These requirements are met by using a body mounted solar array which will have an initial average power output of 37 watts. The output at the end of one year's operation in the S^3-A orbit will be approximately 24 watts. The battery selected for this mission will be an 18 cell, 3 ampere-hour, silver-cadmium battery.

In following the basic S^3 philosophy of system flexibility, certain provisions are made in the power system design. With regard to the conversion electronics, the regulators are designed to handle power increases to 60 watts. Higher ampere-hour batteries could be used, keeping 18 cells in series. The system can also accommodate nickle-cadmium cells by minor modifications to the battery regulator. Additional solar array power can be achieved by supplementing the body mounted array with fold-out panels or paddles.

Referring to figure 4 again, the interface with the experiments is kept as close as possible to the experiment detectors. This will facilitate interfacing with different experiment complements from mission to mission. The signal line flow will be discussed in later sections describing the basic spacecraft subsystems.

Data Handling System

From the beginning of the program, we have considered data handling to encompass an entire system beginning with the output of sensors in the spacecraft and ending in a data tape and data display for the experimenter. Thus, the on-board and ground portions of the data system will be well integrated at all times.

The on-board data handling system is the heart of the spacecraft. Flexibility in this system is most important if we're to achieve the overall program objectives. This point was clear after reviewing the results of our initial interviews with experimenters to solicit design guidelines. As the design of the data handling system progressed, the experimenters were invited to review our plans. Representatives of twenty-one experiment groups visited the GSFC in May, 1967 to participate in this review. This participation in the data system design by the investigators should maximize the scientific return from the flight missions.

An interesting change in philosophy on the part of many experimenters had occurred between the time of our first interviews in mid-1965 and the review in May, 1967. Our initial inquiries regarding on-board processing to reduce transmission of raw data were met with some hesitation and resistance. In the past, most experimenters have wanted every single data point collected by their sensors. After considering the proposed S^3 system, they began to favor our ideas for better utilization of telemetry space. Some experimenters now suggested that we provide even more preprocessing capability than presently planned. Initially they were concerned with the complexity of our system; now, they were suggesting we add arithmetic modules to handle on-board computations. However, for reasons of reliability and overall weight and power limitations, it was decided to provide only a data handling system and not a small computer.

The S^3 on-board data handling system provides a much greater degree of flexibility than most experimenters are accustomed to in the past or present spacecraft programs. This flexibility is possible through the use of stored programs in the system for the collection of data, and through the provision of a greater variety of techniques for sampling the experiment data lines.

Figure 6 is a block diagram of the on-board data handling system. The blocks represent the actual physical components or modules of the system. The system is designed on a modular basis so that certain of the modules need not be used for a particular mission. There are two memory units in the system; a buffer memory with the main function to store experimenters' data, and a program memory which contains the stored programs. The input/output or I/O module contains the necessary conversion devices and multiplexers to receive the various types of signal inputs from the experimenters' input lines and convert them to the correct data form before being sent to the central processing unit or CPU. The CPU provides all of the system functions. It contains the necessary logic for controlling the flow of data words and instruction words through the other modules. The two memory units and the CPU will be standard modules. The makeup of the I/O module will be variable from mission to mission, since it is not known exactly what types of signal inputs will be handled on any particular mission.

The most important feature of the system is the programmable data formats of which there are two types. One is the normal telemetry format which constitutes the telemetry output to the tape recorder; the other is an optional format which is organized into the buffer memory. The data formats are under control of the program memory. New programs can be loaded into the memory at any time before launch or while the spacecraft is in orbit. The programs are loaded in through the command system. This means that the experimenter can alter his data collection format at any time during the life of the mission. He can conduct experiments in space in much the same manner as in the laboratory. During a mission, the experimenter can optimize the coverage of specific events by changing the sampling rates of particular sensors. If a sensor becomes noisy or inoperative, the telemetry space can be utilized by other sensors still providing good data. The reprogrammable format memory words will be transmitted and subsequently used by the ground processing computer so that a single computer program can automatically handle in-flight format changes.

Not all of the telemetry channels are programmable. There are a number of fixed channels for spacecraft functions such as sync, frame parity, frame counter, program instruction words and system status. These requirements are well known in advance and it is desirable to have these functions fixed to facilitate trouble-shooting during spacecraft integration and checkout.

Let us look at the operation of the system. The operation begins by calling instruction words out of the program memory. The CPU decodes the instruction, and in the case where an experiment line is to be sampled, the address of the input line is sent to the I/O, the appropriate conversion is performed, and the resultant word is routed through the CPU to either the buffer memory or to the tape recorder. Note on the diagram the reference to two types of data, Program I and Program II, both of which are stored in the program memory. Program I is responsible for filling the programmable channels of the telemetry format which flow to the tape recorder. When a Program I instruction is processed in the CPU and a sample is taken from a signal input line, the resultant word is passed directly through the CPU to the tape recorder. The time base used to collect Program I data is the normal spacecraft clock. However, when a Program II instruction is processed, the resultant data word must first be stored in the buffer memory. These words will be read out later by Program I instructions.

The Program II feature makes available some relatively new sampling techniques. Most notable of these is a provision for nonsynchronous collection of data. This method requires the use of a program stored in the program memory which collects data in sync with a clock that is completely independent of the normal spacecraft clock. An example of this mode is the collection of data in sync with the spacecraft roll rate. Another sampling technique is the recording of time of randomly occurring events such as the passage of stars through the field of view of a star scanning device. Also, several detectors can be sampled at a high time resolution rate. With this method, it is possible to collect a burst of data, in the order of thousands of bits, at a rate considerably higher than the normal sampling rate. Such a burst of data would be loaded into the buffer memory and then read into telemetry over a much longer period of time than it took to collect the data. Quasi-simultaneous sampling can also be performed. It is possible to sample a number of signal input lines successively and, by using the buffer memory, simulate the sampling of all the detectors at the same point in time.

It is not possible within the context of this paper to completely describe the operation of the on-board data handling system. I will conclude this section with a brief description of the basic characteristics of the modules comprising the system.

The program memory is composed of 256 instructions of 14 bits each for a total of 3,584 bits. It operates in a read-only mode, 14 bits parallel. As previously mentioned, the memory is reprogrammable by ground command. It is designed as a random access, word select, nondestructive readout device in order to provide the most assurance that the program will remain intact through operation of the spacecraft.

The buffer memory contains 4,000 words of four bits each for a total of 16,000 bits. The design is modularized so that the size of the memory can be reduced in 2,000 bit increments. The buffer memory is designed as a random access, coincident current, destructive readout device. It reads and writes four bits parallel and, as previously mentioned, stores data collected under Program II.

The CPU handles all the logic for the system. It contains such devices as instruction decoders, the spacecraft clock, and the data sync clock that is associated with Program II. The CPU also contains the buffer memory address control, program memory address control, index register control of two types, event time recording control, priority control, data routing, fixed format generation, high time resolution control, and timing and control functions. The timing and control functions are available to the experimenters to maintain their collection of data in sync.

As previously mentioned, the makeup of the I/O module will vary from mission to mission. Typical submodules are A/D converters of 8 and 10 bit accuracies that will operate with a conversion time of 100 microseconds. There are accumulators with programmable gates, i.e., the gate which controls the flow of pulses into the accumulator can be opened and closed through the program instruction words. The accumulators can be up to 20 bits in length and can accumulate pulses with frequencies to one megacycle. A word compressor will take the contents of the accumulators and compress them to an 8 or 9 bit word to be sent to the CPU. This is done to conserve telemetry bandwidth and provide a constant accuracy word. There are addressable analog multiplexers that make it possible to handle a number of analog lines into the same A/D converter. The digital multiplexers are also of the addressable variety, and both types of multiplexers are expandable in blocks of 8 to suit the particular mission. The system is capable of handling up to 64 inputs of any type signal. Finally, there is a multiplexer for the high time resolution channel and a subcom multiplexer. The total system for the S^3-A mission will weigh between 4 and 5 pounds and draw approximately $4\frac{1}{2}$ watts.

In order to load the program memory while in flight, a fairly sophisticated command system is required. Previously, the small, Explorer-class satellites have used a sequential tone system to provide a limited number of commands for on-off functions and operating mode changes. However, the time required to load memory with this system would be prohibitive. Consequently, the command system on board the S^3 will be of the PCM instruction type. The system has a bit rate of 128 bits per second and a word format length of 64 bits. Of the 64 bits, a data field of 29 bits is available for possible use each frame. The on-board data handling system accepts 22 bits which determine storage locations and store 14 bits. The remaining 7 bits in the data field can be used to provide up to 128 spacecraft commands. The S^3-A mission will utilize only 6 bits for 64 spacecraft commands. The remaining bits in the 64 bit word format length are used for synchronization, addressing, mode selection, and parity checks. Seven parity bits are used in conjunction with an error detection decoder to facilitate error-free loading of the data handling system and prevent generation of erroneous spacecraft commands. It will take approximately $2\frac{1}{2}$ minutes to change the entire data format. The command system will weigh less than 2 pounds and draw slightly less than 1 watt.

The S^3 spacecraft will use a tape recorder for large capacity on-board storage. With a tape recorder in the system the amount of ground station coverage for data acquisition is minimized. For polar orbit missions, a recorder is essential due to the absence of sufficient station coverage in the northern hemisphere. An endless loop recorder design has been chosen for minimum weight and power. The recorder can hold up to 300 feet of tape, with a packing density of 3,000 bits per inch, giving a total storage capacity of 10.8×10^6 bits. The tape speed upper limit of 15 inches per second gives a maximum input and output bit rate of 45 kilobits per second. The ratio of record to playback speeds may be selected for each mission in the range 50:1 to 1:50. Binary ratios are preferred for ground processing convenience. A playback to record ratio of 32:1 has been chosen for the S^3-A mission. With an input bit rate of 440 bits per second, the output rate will be 14,080 bits per second and the record time will be 6.8 hours. The orbital period for this mission will be slightly more than 7 hours so we will have almost complete orbit coverage. In the event of recorder failure, the recorder can be bypassed and the data stream sent directly to the transmitter. The recorder will weigh approximately 6 pounds and draw $1\frac{1}{2}$ watts.

The S^3 spacecraft will have a transmitter that will operate at two different power levels. Under normal operation, the high power mode will be turned on only when data is being transmitted from the tape recorder. The low power mode will be used for real time transmission when required. The transmitter will operate in the 136 to 138 megahertz band. The antenna system consists of four dipole antennas spaced 90 degrees apart on the surface of the spacecraft cover. The elements form a canted turnstile and are fed from a coaxial hybrid diplexer in phase quadrature to produce a standard IEEE radiation pattern. Tracking will be accomplished with a range and range-rate system or with interferometer tracking depending on the experimenters' requirement for orbital position accuracy.

Error detection coding[2] will be used to provide a continuous check on the data handling system's integrity for proper data quality control. There are many sources for bit errors in the telemetry system due to additive thermal noise, data dropouts from on-board and ground tape units, synchronization errors and momentary antenna nulls. A full frame length, distance 4, cyclic Hamming code has been selected for the S^3 telemetry. This code requires only 1% of the total data frame for parity bits.

Aspect Determination

Two aspect determination systems are available depending on the aspect accuracy required by the experimenter. A system utilizing a digital solar sensor and earth detectors provides aspect accuracies to $\pm\frac{1}{2}$ degree. A star mapping system termed Scanning Celestial Attitude Determination System (SCADS) is being developed which will determine the spacecraft attitude to within ± 0.1 degree or better.

SCADS optically scans an annular ring of the star field. A telescope with a slit shaped field scans the celestial sphere. The system is designed to detect the relative magnitude of the stars crossing the slit and measure their crossing times or angular separation. These measurements, together with a predetermined star map, provide the star identification and the resultant spacecraft orientation. For a spin stabilized spacecraft, the scanning motion is provided by the natural spinning of the spacecraft. In the case of an inertially stabilized application, a motor is included to rotate a scanning disc with respect to the spacecraft. The SCADS for a spin stabilized application consists of a telescope, reticle, photodetector and signal processing electronics. The reticle is opaque except for a fine radial slit centered in the focal plane of the telescope. The photodetector is located behind the reticle. The system operates with stars on the order of fourth magnitude and brighter. It is designed to accept all scanned stars brighter than the selected magnitude and reject those which are dimmer. The star map received by telemetry is compared with a reference map constructed to cover that portion of the celestial sphere selected through a prior knowledge of the orbit and attitude characteristics. The spacecraft attitude will be automatically computed by a least square fit or by cross correlation with the predetermined star data. The system for the S^3-A mission will weigh approximately $3\frac{1}{2}$ pounds and draw less than 0.5 watt.

Attitude and Spin Control

The attitude and spin control system (ASCS) being developed for S^3 is based on the magnetic torquing principal and will provide a means of adjusting the spin axis direction and control of the spin rate throughout the spacecraft mission. For S^3-A, the ASCS will be used to maintain the spin axis-sun angle in the 20^o to 70^o region (0^o being the top of the spacecraft) while maintaining the spin axis within ± 5 degrees of the orbit plane, and to maintain the roll rate of the spacecraft at 4 ± 0.4 RPM.

The two functions of the ASCS, attitude and spin, are essentially independent. Both consist of "vacuum-core" coils made with hundreds of turns of fine aluminum wire epoxied in a fiberglass form. Control torques are developed by the interaction of the magnetic moment of the coils with the earth's magnetic field. Vacuum-core coils are being used in deference to the magnetometer experimenter on the first mission. The spin rate coil is mounted in the top section of the spacecraft in a plane parallel with the spin axis. It consists of some 2000 turns of AWG #31 wire (6900 feet total length) and weighs approximately 1 pound. The power to the coil is switched twice per roll period in accordance with the output of the ASCS magnetometer sensor to develop motor action; hence, a pulsating torque is developed. The spin axis attitude coil is also mounted in the top section of the spacecraft but in a plane perpendicular to the spin axis. It consists of approximately 875 turns of AWG #29 wire (5400 feet) and weighs an estimated 1.1 pounds. The torque generated by this coil will be constant.

The ASCS will be activated by command; however, application of power to either of the coils will be done by the on-board magnetometer. During an in-bound pass, as the satellite approaches perigee, the magnitude of the ambient magnetic field increases. When the magnetometer senses a predetermined field strength level, power will be applied to the coil. Power is removed from the coil on the out-bound portion of the pass when the field strength falls below the threshold level. The value of the field strength chosen is based on a unique design approach which selects system design parameters based on the minimization of the energy-weight product. A direct "on" and "off" command control mode is also possible.

It is expected that a duty cycle of once every several orbits will be sufficient to maintain the desired orientation and spin rate. The total ASCS will weigh approximately 3.5 pounds and will require less than $1\frac{1}{2}$ watts to operate. Other control systems such as cold gas or subliming solids are available depending on mission requirements.

Concluding Remarks

The S^3 design philosophy is based on guidelines obtained through extensive interviews with potential users from the scientific community. The flexible spacecraft system should accommodate a wide variety of scientific missions to be flown in the next decade. Following is a list of the basic S^3 characteristics:

- 80 to 150 pound total spacecraft weight
- 10 to 50 pound experiment weight
- 28 watt power budget at launch
- 9 watts for experiments (10% eclipse)
- 1 year nominal lifetime
- 23 watt power budget after 1 year
- 5 watts for experiments after 1 year (10% eclipse)
- 27 inch spherical shape approximated by octagonal structure
- Suitable for Scout launch
- Obtains flexibility by employing a modular concept to spacecraft subsystems
- Reprogrammable on-board data handling system

Also allows:

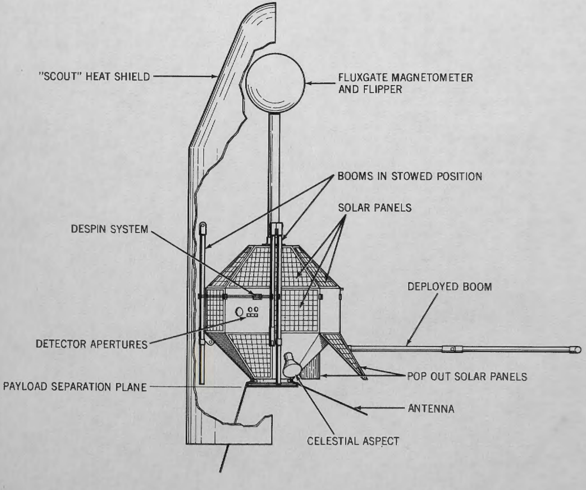
- Approximate 18 month turn-around from experiment proposal acceptance to launch
- Payload integration begins 6 months before launch

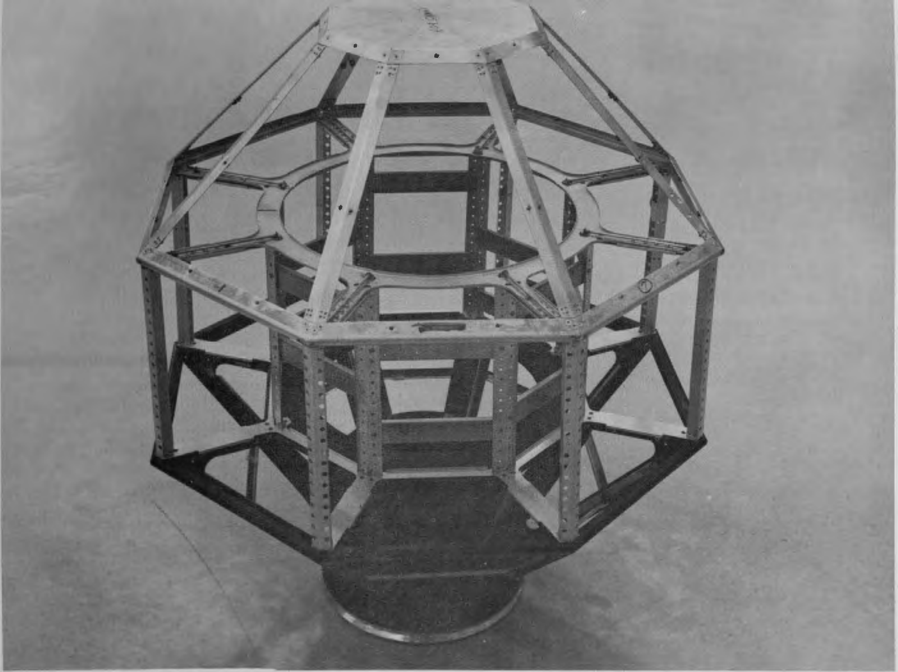
References

(1) Longanecker, G. W., Williams, D. J., and Wales, R. O.; "Small Standard Satellite (S^3) Feasibility Study," GSFC Document X-724-66-120, March 1966.

(2) Saliga, T. V.; "The Small Scientific Spacecraft's Error-Detecting Telemetry Code," GSFC Document X-711-67-582, November 1967.

S^3-A CONFIGURATION





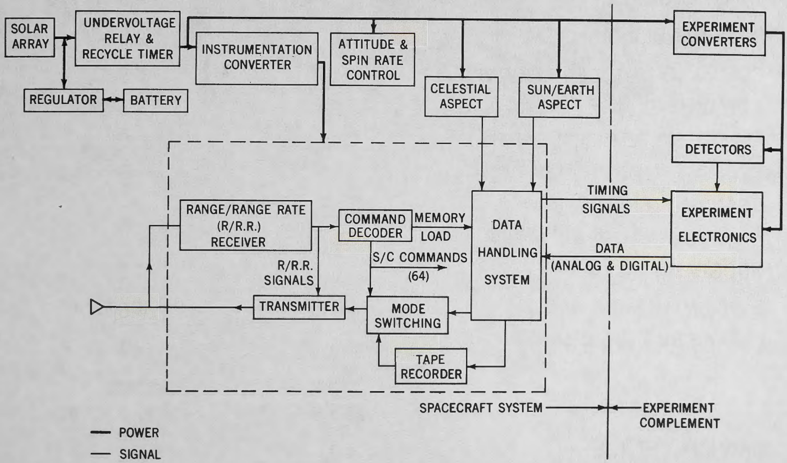
S^3 Engineering Test Unit Structure

S^3–A WEIGHT SUMMARY

SPACECRAFT	ESTIMATED WEIGHT (POUNDS)
DATA HANDLING	13.5
POWER	22.0
RF SYSTEM	5.5
ASPECT DETERMINATION	5.0
ATTITUDE & SPIN RATE CONTROL	3.5
PROGRAMMING & DIGITAL COMMAND DECODER	4.0
STRUCTURE	19.0
HARNESS	6.5
SPACECRAFT TOTAL	79.0
EXPERIMENTS, S^3–A	
MAGNETIC FIELD EXPERIMENT	12.5
PARTICLES EXPERIMENT	10.5
S^3–A EXPERIMENT TOTAL	23.0
S^3–A TOTAL	102.0

17.3-10

BASIC S[3] BLOCK DIAGRAM

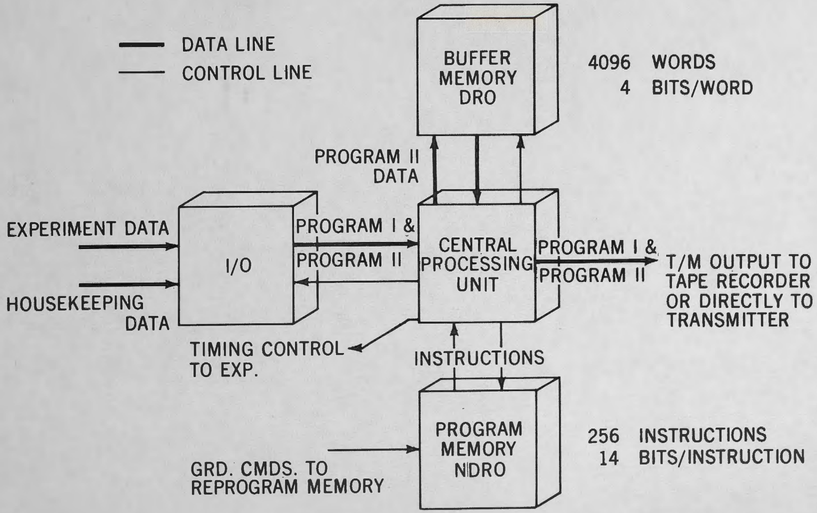


S^3—A POWER BUDGET

	RECORD (95% ORBIT TIME)	PLAYBACK (5% ORBIT TIME)
TAPE RECORDER	1.5 WATTS	1.5 WATTS
DATA HANDLING SYSTEM	5.0	2.5
COMMAND DECODER, RECEIVER, RANGE & RANGE RATE	0.5	0.5
ASPECT SYSTEM: SUN/EARTH	0.5	0.5
CELESTIAL	0.5	0.5
TRANSMITTER: LOW POWER	1.5	–
HIGH POWER	–	15.0
PROGRAMMER	0.5	0.5
EXPERIMENTS	4.6	4.6
LOSSES (CONVERTERS)	2.9	2.1
SUBTOTAL	17.5 WATTS	27.7 WATTS
BATTERY CHARGE	4.0	–
TOTAL	21.5 WATTS	27.7 WATTS

17.3-12

BLOCK DIAGRAM S^3 DATA HANDLING SYSTEM



17.3-13